LCA Discussions

Efficient Information Visualization in LCA: Approach and Examples

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DOI: http://dx.doi.org/10.1065/lca2003.08.130

Abstract

Aim, Scope and Background. The data-intensive nature of life cycle assessment (LCA), even for non-complex products, quickly leads to the utilization of various methods of representing the data in forms other than written characters. Up until now, traditional representations of life cycle inventory (LCI) data and environmental impact analysis (EIA) results have usually been based on 2D and 3D variants of simple tables, bar charts, pie charts and x/y graphs. However, these representation methods do not sufficiently address aspects such as representation of life cycle inventory information at a glance, filtering out data while summarizing the filtered data (so as to reduce the information load), and representation of data errors and uncertainty.

Main Features. This new information representation approach with its glyph-based visualization method addresses the specific problems outlined above, encountered when analyzing LCA and EIA related information. In particular, support for multi-dimensional information representation, reduction of information load, and explicit data feature propagation are provided on an interactive, computer-aided basis.

Results. Three-dimensional, interactive geometric objects, so called OM-glyphs, were used in the visualization method introduced, to represent LCA-related information in a multi-dimensional information space. This representation is defined by control parameters, which in turn represent spatial, geometric and retinal properties of glyphs and glyph formations. All relevant analysis scenarios allowed and valid can be visualized. These consist of combinations of items for the material and energy inventories, environmental items, life cycle phases and products, or their parts and components. Individual visualization scenarios, once computed and rendered on a computer screen, can then interactively be modified in terms of visual viewpoint, size, spatial location and detail of data represented, as needed. This helps to increase speed, efficiency and quality of the assessment performance, while at the same time considerably reducing mental load due to the more structured manner in which information is represented to the human expert.

Conclusions. The previous paper in this series discussed the motivation for a new approach to efficient information visualization in LCA and introduced the essential basic principles. This second paper offers more insight into and discussion on technical details and the framework developed. To provide a means for better understanding the visualization method presented, examples have been given. The main purpose of the examples, as already indicated, is to demonstrate and make transparent the mapping of LCA related data and their contexts to glyph parameters. Those glyph parameters, in turn, are used to generate a novel form of sophisticated information representation which is transparent, clear and compact, features which cannot be achieved with any traditional representation scheme.

Outlook. Final technical details of this approach and its framework will be presented and discussed in the next paper. Theoretical and practical issues related to the application of this visualization method to the computed life cycle inventory data of an actual industrial product will also be discussed in this next paper.

Keywords: Glyph rendering; information visualization; life cycle assessment (LCA); life cycle inventory; life cycle data set mapping; multi-dimensional information space

1 Aim and Scope

The data-intensive nature of life cycle assessment (LCA) means that various methods and computer-based tools are required for storage, management and representation of all the information being acquired and collected for analysis. Information visualization, in particular, is an important issue, since visualization is a means to aid understanding, and understanding, in this context, is vital for a successful analysis. In interpreting both life cycle inventory (LCI) and environmental impact assessment (EIA) results (ISO14040), there is considerable scope for developing specialized visualization methods. The traditional methods of representing LCI and EIA data are based on 2D and 3D variants of simple tables, bar charts, pie charts and x/y graphs. However, these representation methods do not sufficiently address aspects such as representation of life cycle inventory information at a glance, filtering out data while summarizing the filtered data (so as to reduce the information load), and representation of data uncertainty. Visual representations are easier for humans to understand due to their perceptual capabilities for detecting spatial structures and shapes in different colors and textures. Therefore, pictorial representation in the form of a glyphs, a special class of (interactive) three-dimensional geometric object, has been utilized to address the above problems. Different parameters describing spatial, geometric and retinal properties of such glyphs, and defining their position, orientation, shape, color, etc., are used to encode more information in a comprehensible format, allowing for visualization of a multi-dimensional information space. This approach provides an expert with sufficient information to see major contributors to the life cycle of a product at a glance. Additionally, and in parallel,

the understanding of data uncertainty, less significant contributors (filtered-out data) and data feature propagation is aided by this means of information visualization.

The first paper of this short series on efficient information visualization in LCA introduced the motivation for this novel approach and discussed the basic concept and some fundamental principles of glyph-based visualization techniques. Now, this paper, the second in the short series, introduces more technical details of the approach and the framework implemented. Issues concerning individual visualization scenarios and the mapping of LCA-related data and contexts are presented and discussed. There is further discussion, with examples of techniques used for the visualization of data uncertainty, and of filtered absolute and relative contributions to quantities of energy requirements and environmental items, both as related to individual life cycle phases, and as products or their parts and components. As already outlined at the beginning of this series, further details regarding the structure of spherical glyph clusters, and aspects of application and translation into practice, will be offered in the next paper, together with examples using real industrial product data.

2 Background

Since a detailed background on information visualization and LCA has already been provided in the previous paper of this series (Otto, Mueller, Kimura 2003), in this section only a brief review will be given accompanied by a small selection of references to relevant work.

As indicated earlier, visual representations are easy for humans to understand, due to our perceptual capabilities for distinguishing spatial structures and shapes presented in different colors, textures and shadings. Information visualization, the process which transforms and maps data and its context to a visual representation, can be used to take advantage of these human perceptual capabilities. Early work on theory and principles of pictorial representations, sharing one or more properties with the items which they represent, goes back more than one decade (Feibleman 1969, Chang 1989). One particular class of such graphical objects acting as a pictorial representation, is glyphs. Some representative work on the development of glyphs and their successful application can be found in (Ribarsky et al. 1994, Post et al. 1995, Abello et al. 2000). Although it is a very promising field with immense potential, neither fully understood nor completely explored yet, the issue of finding the best design for meaningful glyph shapes represents one of the major frontiers in multidimensional information visualization (Parker et al. 1992, Ebert et al. 2000). Further work on information visualization, discussing examples, taxonomies and analysis of point designs, including an extensive list of references in this field, can be found in (Card et al. 1999).

3 Approach

3.1 Outline and brief review

The basic purpose of any visualization concept is to replace original data with a carefully designed symbolic display. Within the approach as introduced, glyphs are used as symbolic representations showing the essential characteristics of the LCA-related data domain to which they are linked.

The set of glyph attributes that define the number of degrees of freedom, i.e. the glyph's set of control parameters, can be divided into three major groups. First, *spatial parameters* that define position and orientation. Second, *geometric parameters* that define the shape. Third, *descriptive parameters* that define texture, color, transparency, opacity, saturation and sound. Thus a glyph's degrees of freedom can be specified as a domain consisting of a combination (cross product) of the spatial, geometric, retinal and acoustic domains.

Data within a known context, i.e. knowledge of a discourse subject to analysis and visualization, can be abstracted as a *reference domain*. A selection of these data (the reference domain) which is important in a particular respect can be abstracted as a *selection domain*. The space in which a glyph exists can be abstracted as its *appearance domain*, a combination (cross product) of the *display domain* that contains all graphical objects allowed and the *acoustic domain* that contains all sound and voice items allowed. Note that within the scope of this paper, the appearance domain is equal to the display domain, because the advantage of acoustic parameters is not yet clearly anticipated in this application. The structural generation of a glyph, i.e. the computation of proper glyph attributes based on a selection of characteristic data, can be abstracted as a mapping from the selection domain to the appearance domain specified by the relationships between the data to be visualized and the sets of control parameters discussed earlier. Finally, a glyph-based information visualization space can be abstracted as a *glyph domain* that consists of an ordered mapping of the reference domain, the selection domain and the appearance domain.

3.2 Formal structures and test environment

The first paper in this series presented the basic principles of the approach and gave an informal introduction to OM-glyphs. Now it is time to take a closer look at the formal structure of those glyphs. This small section and the following section, mostly written in an informal style, are intended to further aid understanding of the approach itself and of the examples given later in this paper.

The single ellipsoid $e \in E$, the basic component of OM-glyphs, is a special quadratic surface with a symmetry point representing a bound, closed point set $\boldsymbol{\mathcal{E}}$, within the Euclidean point space E^3. However, to describe ellipsoids that are attached to another ellipsoid or a sphere that is located at the center of a glyph, the definitions as presented in (Otto, Mueller, Kimura 2003) need to be rewritten, by including a displacement of the ellipsoid center as shown in Eq. 1,

$$(x - x_0)^T A' (x - x_0) = 1 \qquad (1)$$

where A' is a positive-definite matrix and x_0 the new center of the ellipsoid. Thus, an instance ε of the bound, closed point set $\varepsilon \in \boldsymbol{\mathcal{E}}$ of an ellipsoid e is defined by the ordered pair $\varepsilon = (x_0, A')$ that represents *spatial* and *geometric parameter* properties. The ellipsoids which form part of the glyph, in addition to their point sets ε, contain further *descriptive*

parameters such as color *(C)*, saturation *(S)*, transparency *(T)*, opacity (O) and behavior *(B)* which are summarized in Eq. 2. This defines the complete structure of the components of the glyph in relation to its ellipsoids.

$$E = (\boldsymbol{\mathcal{E}} \times C \times S \times (T + O) \times B) \qquad (2)$$

An OM-glyph consists of a set of connected ellipsoids with one ellipsoid $e \in E_0$ at the center, which, in the case of data being visualized without error or uncertainty, is an ellipsoid with three identical half-axes $a = b = c$ with $a, b, c \in \mathbf{R}^+ \setminus 0.0$, resulting in a sphere. To provide a mechanism to prevent the visualization of unnecessary or insignificant data (user controlled reduction of glyph dimension, see below), each glyph contains a filter function $\psi\colon \mathbf{R}^+ \rightarrow (\mathbf{B} \times \mathbf{R}^+)$ which prevents visualization of parameters with values below a given (filter) threshold. However, if the sum of the filtered parameter values is of interest, visualization can be provided by an additional ellipsoid or sphere $e \in E_\psi$ embedded in the center of the glyph. To improve its appearance, it is rendered with modified parameter values regarding saturation and transparency. A complete OM-glyph, as shown in Fig. 5, is defined in Eq. 3.

$$G = (\psi \times E_\psi \times E_0 \times (E_i \times E_m \times \ldots \times E_n))$$
$$i = 1 \text{ and } n = max(\Theta\,(g)) \qquad (3)$$

The glyph dimension $\Theta: G \rightarrow \mathbf{N}^+$ of the OM-glyph is defined as the number of individual LC related parameter values being explicitly visualized, each as an ellipsoid e_i with $i \in \mathbf{N}^+$, within the glyph. For example, the dimension of the glyph shown in Fig. 5 is $\Theta = 6$, which indicates that information about six individual LC-related parameters is being explicitly visualized. Note that the glyph dimension Θ represents a quantitative partial measure for the amount of information being visualized within a single glyph and should not be confused with the geometric dimensions of a glyph, which are linked to its visual appearance within the three-dimensional Euclidean space.

The hardware platforms employed to compute data for the product life cycle inventory, and to generate all rendered glyphs as shown later in the section on information visualization and examples, consisted of multi-processor Intel® Xeon™ powered, Microsoft® Windows® 2000 Professional operated graphics workstations.

3.3 Visualization scenarios and data / context mapping

Within a given scope, the following visualization scenarios, considered important for LCA experts, are supported:

(i) Displaying the importance of individual life cycle phases in regard to one environmental item or one item from either the material inventory or the energy inventory.

(ii) Displaying the importance of several environmental items or several items from either the material inventory or the energy inventory in regard to one life cycle phase.

To support various viewpoints during the assessment process, regarding the degree of detail, these visualization scenarios can be related to the entire product, or to its components, or to individual parts.

Most of the LCA-related information can be represented numerically (truth values and non-numerical evaluation scales and classification schemes can be mapped to natural numbers). Therefore, a matrix of a higher dimension can be used as an efficient interim data structure to provide both a structured data access for the visualization scenarios as outlined above and a means to store all computed parameters required to generate all entities of the multi-dimensional information visualization space, as defined within the appearance domain. From a theoretical point of view, any formal structure such as nested variant records or structured double-linked lists (Aho et al. 1983, Wirth 1986) could be used for this purpose. However, matrices are widely understood (Watkins 1991, Golub and Loan 1996), with many computer-based optimizations available (Gilbert et al. 1992, Im 2000) and have structural similarities to the LCI tables which are used by LCA experts, so preference was given to their use. Basically, a five-dimensional numerical matrix can be used to represent basic LCA data related contexts with each of its rows and columns, respectively, as follows. The first dimension encodes the product, its components and single parts. The second dimension encodes environmental items or items from either the material inventory or the energy inventory. The third dimension encodes individual LC phases. The fourth and fifth dimensions encode summarized values of relative and absolute contributions for both regular values and filtered-out values. When data errors or data uncertainties are being considered during computation and analysis, the rows and columns, respectively, of the second and third dimension of the interim data matrix each need to be exchanged for a two-dimensional sub-matrix, providing access and storage for upper limit and lower limit data values, instead of for one error-free, accurate value alone. To accommodate the access structure of the data matrix to the structure of a chosen visualization scenario, note that the encoding of the second dimension and the third dimension can be exchanged. During data mapping, which is based on LCA-related data sets from the selection domain, first all basic input parameters are retrieved. Next, all data required to fill the cells of the data matrix, as outlined above, are computed, standardized and normalized. After all cells of the matrix have had their values assigned, actual calculation of the parameters used for the generation of the glyphs can be commenced.

Data and their contexts, once retrieved, computed and stored in a systematic and structural way as outlined, are then ready to be mapped to their visual representations as follows. Individual LC phases, environmental items and items from the material inventory and the energy inventory are encoded as colors of (geometrical) glyph components such as the central sphere and the attached ellipsoids. In the case of large glyph matrices, individual glyph annotation in the form of attached background text can also be used (Otto and Mueller, 2002). The actual value of these items, as well as their sum, is represented in the size of glyph components, using explicit or implicit, volume-based or surface-based calculations as described in (Otto, Mueller, Kimura 2003). The data quality, i.e. proportion of errors and uncertainty, is represented as shape distortions of the glyph's spheres and ellipsoids, resulting in oblate spheroids or prolate spheroids (Otto,

Mueller, Kimura 2003). LCA data related to a single product, or to one component, or to single parts, are usually encoded within one glyph. In the case of representing data from several components or parts simultaneously, a glyph matrix or a spherical glyph cluster can be used to visualize a chosen scenario, and the spatial location of each glyph denotes to which component or part it refers.

4 Information Visualization with Examples

4.1 Overview

In the following, glyph-based information visualization of a selection of computed LCI data sets will be presented and discussed, and interpretations made. Data used to compile the LCI in the example, a color monitor for a desktop computer, were taken from an integrated product data base courtesy of a large Japanese manufacturer of electronic appliances and computers (Otto and Mueller 2002). Absolute values are proportional to the volume of each sphere, although proportionality to surface area or radius is also considered as practical (see Otto, Mueller, Kimura 2003, p. 187). However, this would result in larger glyph size differences for the same data set in some cases.

As indicated earlier, this example is presented to illustrate the mapping of LCA related data and their contexts to OM-glyph structures. Therefore, the data sets have been kept small and transparent and the product tree has a depth (longest path, i.e. greatest number of edges, from the root node to a leaf node) of only one. The product tree consists of one root node, representing the color monitor, and seven leaf nodes representing cathode ray tube (CRT) assembly, printed circuit board (PCB) assembly, cabinet, packaging box, packaging material, shield, and others (**Fig. 1**).

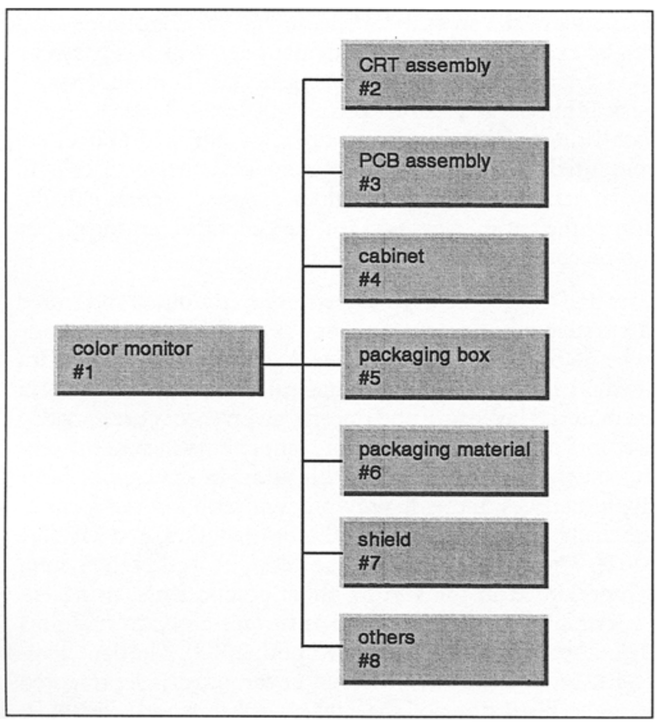

Fig. 1: Simplified product tree for the example

Visualization examples are given for only one environmental item, the air pollutant fossil carbon dioxide (CO_2) in three life cycle phases; pre-manufacturing (PM), use (U), and post-use with disposal (PUD). The profile for the use phase in the example was set to eight hours per day for 200 days per year over a period of three years. The electric power input required was 100 watts. In the following, examples of basic data and context mappings and their visualizations will be presented. Since the data sets and inventories have been kept small to ensure transparency, glyph filters were set to zero in all visualizations, except in case of demonstrating the filter effect itself.

4.2 Basic values and linear filters

Currently, basic values for absolute and relative contributions of LCI quantities, environmental items, materials and energy can be represented within individual visualization scenarios, as introduced earlier. In the following, two examples will be given, visualizing absolute and relative contributions of the air pollutant carbon dioxide in relation to product components and to life cycle phases. The corresponding LCI in table form are shown in **Fig. 2**.

1	Air pollutants	Carbon dioxide fossil	
PM	Total:	42.9863	kg
	% of all	16.6448 %	
Components	Amount	Unit	Percentage
2	27.3185	kg	63.5517%
4	6.2155	kg	14.4593%
5	1.1772	kg	2.7385%
6	3.2800	kg	7.6303%
7	2.9457	kg	6.8527%
8	2.0494	kg	4.7675%

3	Air pollutants	Carbon dioxide fossil	
U	Total:	213.854	kg
	% of all	82.807%	
Components	Amount	Unit	Percentage
1	213.854	kg	100%

7	Air pollutants	Carbon dioxide fossil	
PUD	Total:	1.41579	kg
	% of all	0.54821%	
Components	Amount	Unit	Percentage
1	1.41579	kg	100%

Fig. 2: Basic LCI of carbon dioxide for three life cycle phases

In the first visualization scenario example, as shown in Fig. 3, the absolute contribution of CO_2 relative to each component is represented by the size of each glyph sphere. The sphere of glyph *g(1,1)* (upper left corner in the glyph matrix), for example, representing the contribution of the monitor, is related to a contribution of 83.4%, i.e. 215.3 kg. The relative CO_2 contribution of the monitor in each life cycle phase is visualized by the green ellipsoid (use phase), representing 82.8%, i.e. 213.9 kg, and the cyan ellipsoid (post-

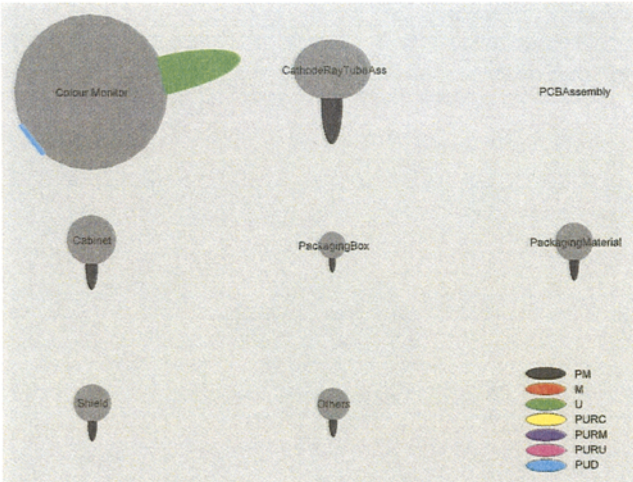

Fig. 3: Carbon dioxide glyph matrix as related to components and life cycle phases

use with disposal), representing 0.5%, i.e. 1.4 kg. Since the CO_2 contributions of all single components, except the monitor itself as a complete product, are zero in the life cycle phases of use and post-use, each glyph in the glyph matrix features only one black ellipsoid (see again basic LCI in Fig. 2). Note that the PCB assembly usually makes a contribution, but in this example data was not available, and would be small anyway. Therefore, the glyph *g(1,3)* is missing in **Fig.** 3.

In the second visualization scenario example, shown in **Fig.** 4, the absolute contributions of CO_2 in each life cycle phase are represented by the size of each glyph sphere. The sphere of glyph *g(1,2)*, also shown enlarged in **Fig.** 5, for example, represents a contribution of 16.6%, i.e. 43 kg, of CO_2 in the pre-manufacturing phase. Relative contributions of individual components in this life cycle phase are represented as follows. The red ellipsoid (cathode ray assembly) represents a relative CO_2 contribution of 63.6%, i.e. 27.3 kg. The yellow ellipsoid (cabinet) represents a relative CO_2 contribution of 14.5%, i.e. 6.2 kg. The magenta ellipsoid (packaging material) represents a relative CO_2 contribution of 7.6%, i.e. 3.3 kg. The cyan ellipsoid (shield) represents a relative CO_2 contribution of

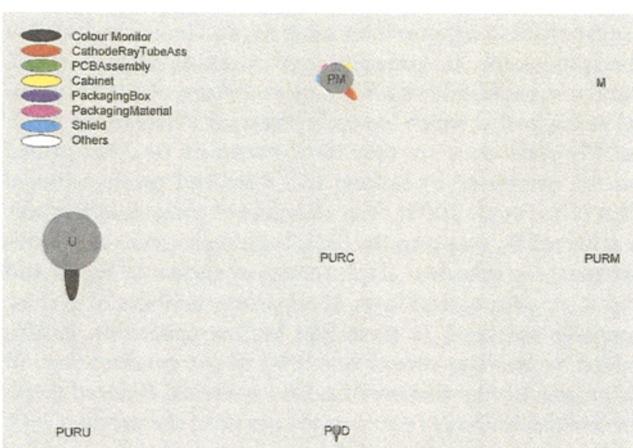

Fig. 4: Carbon dioxide glyph matrix as related to life cycle phases and components

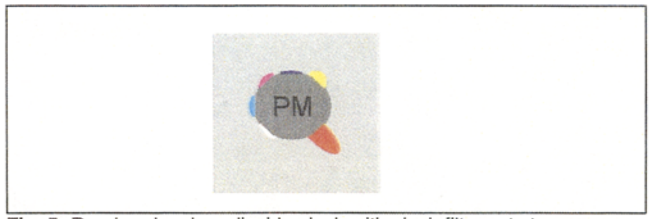

Fig. 5: Rendered carbon dioxide glyph with glyph filter set at zero

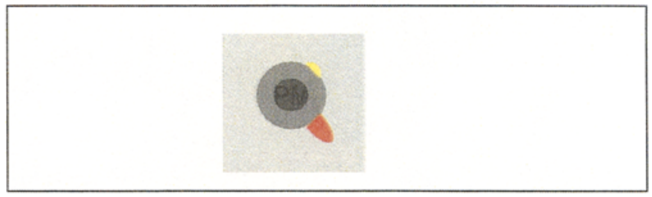

Fig. 6: Rendered carbon dioxide glyph with glyph filter set at 10%

6.9%, i.e. 2.9 kg. The white ellipsoid (others) represents a relative CO_2 contribution of 4.8%, i.e. 2 kg. The blue ellipsoid (packaging box) represents a relative CO_2 contribution of 2.7%, i.e. 1.2 kg. Note that as there is no contribution of CO_2 to other life cycle phases, glyphs *g(3,1)*, *g(2,2)*, *g(1,3)* and *g(2,3)* are missing in the glyph matrix in Fig. 4.

Since all OM-glyphs contain a filter, less significant data can be eliminated before glyph rendering, although the accumulated sum of filtered data (relative contributions in a visualization scenario) can sometimes be of interest. This issue leads to the adoption of rendering the filtered values as an inner sphere. For example, look again at glyph *g(1,2)* in the glyph matrix shown in Fig. 4 where glyph dimension of $\Theta = 6$ (see enlarged image in Fig. 5). If we apply a filter by setting the threshold value of the glyph filter function Ψ to 10% (see again Otto, Mueller, Kimura 2003, p. 186 and previous section on formal structures and test environment), we obtain a rendered glyph with a glyph dimension of $\Theta = 2$ as shown in **Fig. 6.**

4.3 Data errors and uncertainty

To visualize errors and uncertainty efficiently in LCI data sets, a structured glyph shape distortion schema has been developed. Within the basic approach taken, an intermediate mapping has been added to the regular domain mappings. This intermediate mapping acts between data sets from the selection domain and a continuous distribution function modeling the probability of selected values fitting within a given value range. Such an intermediate mapping is required in order to compute the additional geometric parameters necessary to generate consistent data driven shape distortion ranging from spheres and ellipsoids to spheroids. Shape distortion of the central sphere of the glyph is computed as follows. If the mean of a derived distribution function is close to the upper limit of the value range of the selected LCI data set, a disk like ellipsoid (oblate spheroid) is rendered. If the mean is close to the lower limit, an elongated, somewhat stretched ellipsoid (prolate spheroid) is rendered. Minor errors and low uncertainty in LCI data sets will produce an average close to the mean of a related distribution function. This will be visualized as a rendered spheroid, showing only slight shape distortion.

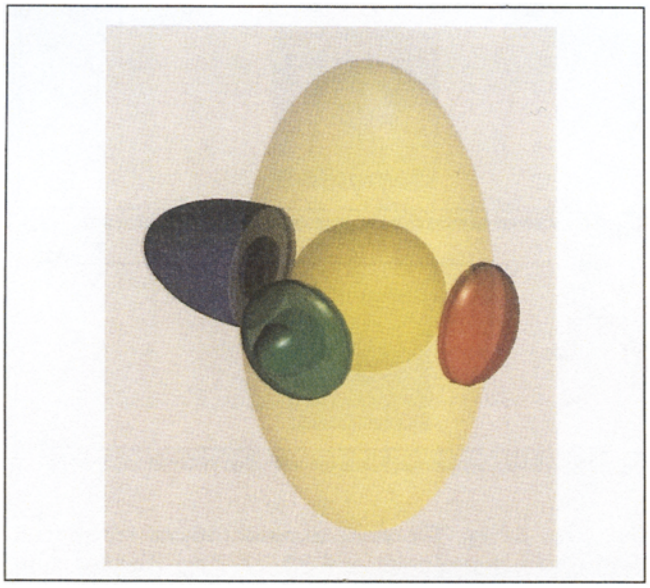

Fig. 7: Example of a rendered OM-glyph visualizing data uncertainty

Since the inventories in the example have been kept small for reasons already explained, no data errors or data uncertainty have been included in the data sets. However, to complete this example section, a small generic example, will be given for demonstration purposes only. An example within a real application for data mapping and visualization of data errors and data uncertainty will be given in a subsequent paper.

Errors and uncertainty in data of relative contributions are visualized as a pair of either stretched or tossed ellipsoids (oblate / prolate spheroids) with shape distortion in the y-z plane in the case of a computed LCI data average closer to the lower limit (outer blue ellipsoid in **Fig.** 7) and shape distortion in the x-z plane in the case of a computed LCI data average closer to the upper limit (red ellipsoid in Fig. 7). Within this glyph shape distortion schema, we can efficiently encode and visualize location (item from material inventory or energy inventory or environmental item in life cycle phase related to a part or an assembly), type (computed average tending towards the lower limit or upper limit), and severity, i.e. potential for possible impact (degree of visualized distortion in the central sphere of the glyph or in attached ellipsoids), of errors and data uncertainty.

4.4 Entity relationships and feature propagation

To provide also for visualization of entity relationships and data feature propagation, spatial glyph formations in the form of glyph matrices and spherical glyph clusters are included in the framework. Glyph matrices are useful for permitting simultaneous visualization of the absolute and relative contributions of more than one entity within a chosen visualization scenario.

Looking again at the CO_2 glyph matrix shown in Fig. 3. Each glyph is linked to a component and a life cycle phase, both related to emissions of carbon dioxide. Several relationships among items can be visualized as follows. The ratio of absolute CO_2 contributions of individual components is represented by the different sizes of the glyph spheres. For example, glyph *g(1,2)* represents 27.3 kg of CO_2 contributed by the cathode ray assembly, while glyph *g(1,3)* represents 6.2 kg of CO_2 contributed by the shield, and so forth. Further relationships, such as the relative CO_2 contribution of each component to each life cycle phase, are indicated by the size and color of each ellipsoid attached to each component glyph in the glyph matrix. Individual examples of relative contributions of CO_2 within each individual glyph have already been discussed in detail in a previous section. Within the glyph matrix presented, relationships regarding both the relative absolute contribution of each part (in respect to the entire product) and the relative contribution of an item within each part in respect to individual life cycle phases can be visualized simultaneously in a transparent and efficient manner. Of course, any other visualization scenario, as outlined earlier, can also be represented and visualized using a glyph matrix.

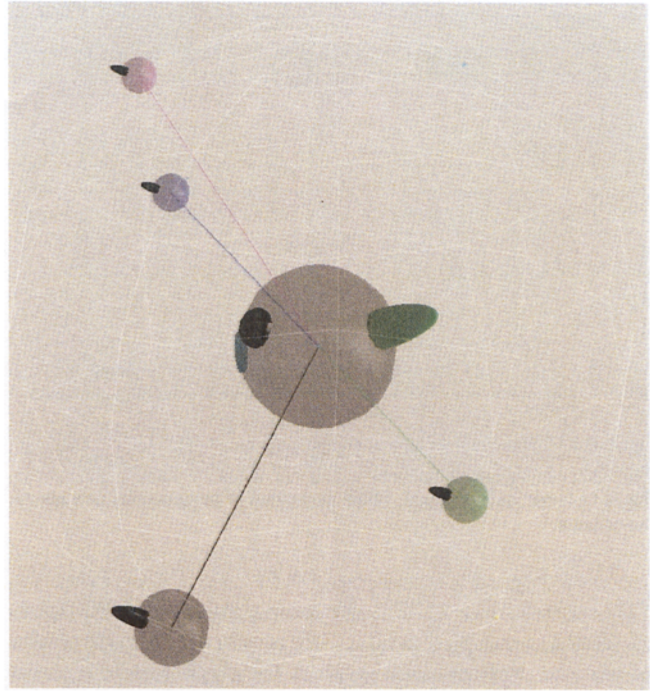

Fig. 8: Spherical glyph cluster for carbon dioxide emissions

Visualization of data feature propagation is yet another important tool to support data analysis, and is also included in the framework. Information vital to LCA, such as which part or sub-assembly causes high emissions of environmental items, and in which life cycle phase, or where in the product life cycle data are they most uncertain or error prone, can be computed by linking LCI data and product model data (Otto et al. 2001). Visualization of these data features is achieved by mapping the basic logical structure of a product tree to a spherical glyph cluster as shown in Fig. 1 and **Fig.** 8. Each spherical layer of superimposed sets of glyphs, spatially arranged as mesh-like hollow spheroids, is also linked to the data sets of one level of the product tree. In other words, the number of nested spherical ordered glyph formations is always equal to the depth of the product tree, with each node and arc of the product tree having a corresponding glyph and glyph cluster arc within the complete spherical glyph cluster.

The spherical glyph cluster in Fig. 8 shows clearly all relative and absolute contributions for the entire product and all components of the product for the environmental item carbon dioxide, while at the same time also representing all (relative) contributions regarding each life cycle phase considered. For example, the central glyph, representing the entire product, shows in its central sphere that the total amount of CO_2 generated in all life cycle phases is 258.3 kg, with accumulated contributions of 43 kg (black ellipsoid) during the pre-manufacturing phase, 213.9 kg (green ellipsoid) during the use phase, and 1.4 kg (cyan ellipsoid) during the post-use / disposal phase. Contributions and relationships for various components, such as the shield (glyph with red sphere at upper left), the cabinet (glyph with green sphere at lower right), etc. are represented in a similar fashion. As in the case of single glyphs and glyph matrices, spherical glyph clusters can be used to represent any visualization scenario, as outlined and discussed earlier.

5 Conclusions

Within the second paper of this small series on efficient information visualization in LCA, further technical details have been presented and first examples containing brief sets of actual product data have been analyzed in order to demonstrate mode and operation of this novel approach. Generated visualizations have shown that real-time interactive information visualization is indeed capable of quickly and efficiently conveying the basic features and relationships of multi-dimensional data sets. Advanced attribute mapping and filtering allow for the elimination of less significant data, and this supports less congested data analysis of relevant information. Introduced spatial glyph formations, such as glyph matrices and spherical glyph clusters, provide a natural means of simultaneously representing complex scenarios, with relationships and data feature propagation, among several entities and their mapped data sets. This information representation is transparent, clear and compact, features which cannot be achieved with traditional representation schemes.

6 Recommendation and Outlook

A sufficient background, of an interdisciplinary nature has been provided, to the subject of discourse. The basic principles and methods have been presented, and, hopefully the technical details and examples discussed in this paper have been understood. In the next paper of this series, additional technical details, especially of the structure of the spherical glyph clusters, will be presented and discussed, and examples will be given demonstrating the application of the approach using data from an actual industrial product, with an implemented testbed developed according to the framework presented.

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Received: July 31st, 2003
Accepted: August 5th, 2003
OnlineFirst: August 6th, 2003

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